The Virtual Venue: User-Computer Interaction in Information-Rich Virtual Environments

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ABSTRACT

We present a virtual reality application that allows users to access embedded information within an immersive virtual environment. Due to the richness and complexity of this environment, interaction between the user and the system requires efficient and easy-to-use techniques. We present tools for user control of the system, travel through the environment, and information retrieval. A usability study and its results are also presented and discussed. The study indicates that the use of symbolic information which is tightly coupled to the virtual environment can be quite successful in enhancing the relevance of both the environment and the information. Results also indicate that the set of well-constrained interaction techniques presented here are usable and efficient for information retrieval.

Keywords

virtual reality, human-computer interaction, information visualization, animation

INTRODUCTION AND RELATED WORK

Many successful immersive virtual reality (VR) applications can be characterized by a low degree of interaction between the user and the system. For example, architectural walkthrough (e.g. [6]) requires only that the user has some technique for moving through the space. Virtual environments (VEs) used for exposure therapy [11] may contain no interactive techniques whatsoever. It is clear, however, that useful applications of VEs exist in which the user does more than look at the environment and move through it.

We propose that information retrieval, for educational or instructional purposes, is one such application. The ways in which people access information have rapidly moved from the simple printed page to the use of audio-visual materials to the World Wide Web and multimedia software titles.

Information retrieval is now characterized by non-linearity, the use of multiple information types, and a greater degree of user control over the presentation and content of the information. It seems natural, then, that we should ask whether certain information might be enhanced for the user if presented and accessed in the context of an immersive, three-dimensional virtual environment. If so, then new or adapted interaction techniques will be necessary to give the user control over the system and easy access to this *embedded information*.

Much of the previous work in the use of VEs as information spaces has focused on *information visualization*. One class of systems deals with scientific visualization in VR, such as the virtual wind tunnel [7], the Virtual Data Visualizer [16], Cosmic Explorer [19] and ScienceSpace [8]. These applications allow the user to visualize animations of abstract objects which represent scientific data.

Another category of systems present abstract *database visualizations* [e.g. 2, 17]. Such applications attempt to organize a complex dataset into an understandable visual representation, which can then be navigated and accessed by the viewer. Both of these types of environments present symbolic or abstract information by converting it to a perceptual form, using color, shape, or texture to represent information attributes.

Our work has a somewhat different focus. We are researching ways that symbolic data relating to an environment may itself be embedded into that environment. In this way users can form links between the perceptual data and the symbolic data which relates to it [3]. Learning and relevance of the information may be enhanced for the user because of this coupling, and similarly, enjoyment of the 3D environment could be augmented since additional information about the environment is available. This is somewhat similar to work in augmented reality [e.g. 9], where virtual information is overlaid onto a view of the physical world.

In this paper, we present an example of such an "information-rich" virtual environment, along with various techniques, tools, and metaphors for simple and efficient interaction between the user and the system. These include a hand-held menu system, a constrained travel technique, spatial hyperlinks, audio help, and three metaphors for information access. We will focus on two questions. Can the use of immersive VR actually enhance the presentation of symbolic information? If so, what interaction techniques can be used to retrieve information easily and to indicate the relationship between the information and the virtual environment? To help answer these questions, we also discuss the results of a usability study performed on the system.

THE VIRTUAL VENUE

Environment

The "Virtual Venue" is a VR application in which users are immersed in a 3D model of the Georgia Tech Aquatic Center (Figure 1). The Aquatic Center has been used as a venue hosting world-class competitions in the sports of swimming, diving, synchronized swimming, and water polo.

The Center contains two pools: a diving well and a swimming pool. It also has a diving tower complex, with 5 diving platforms, as well as 4 springboards. Spectator seating runs the length of the two pools, and the entire complex is open to the outside on the ends, providing views of the Georgia Tech campus and downtown Atlanta.

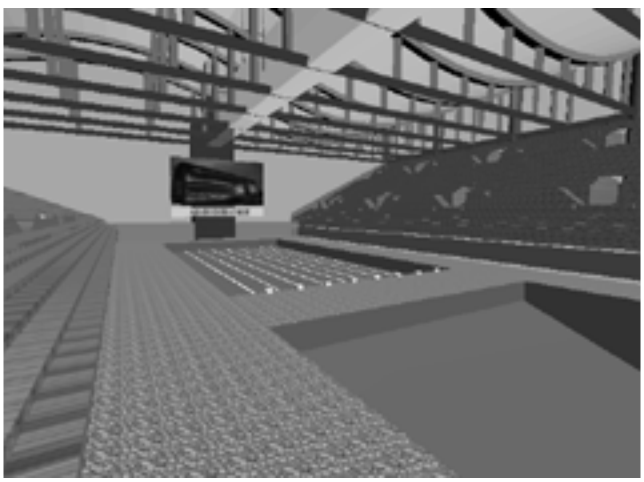


Figure 1. The Virtual Venue Environment

The software is built upon the Simple Virtual Environment (SVE) Toolkit [13], and runs on a Silicon Graphics Crimson with Reality Engine. Tracking is performed by a 3-tracker Polhemus Fastrak, and users wear a Virtual Research VR4 head-mounted display (HMD). A 3-button joystick and/or a stylus are used for input.

Within the system, we have embedded multiple forms of symbolic and perceptual information. These include text, audio, imagery, 3D animation, and "experiential" information. Users of the Virtual Venue can move about the Center and obtain information about the building itself, the events which have been held there, and the sports of swimming and diving.

Hand-held Menu System

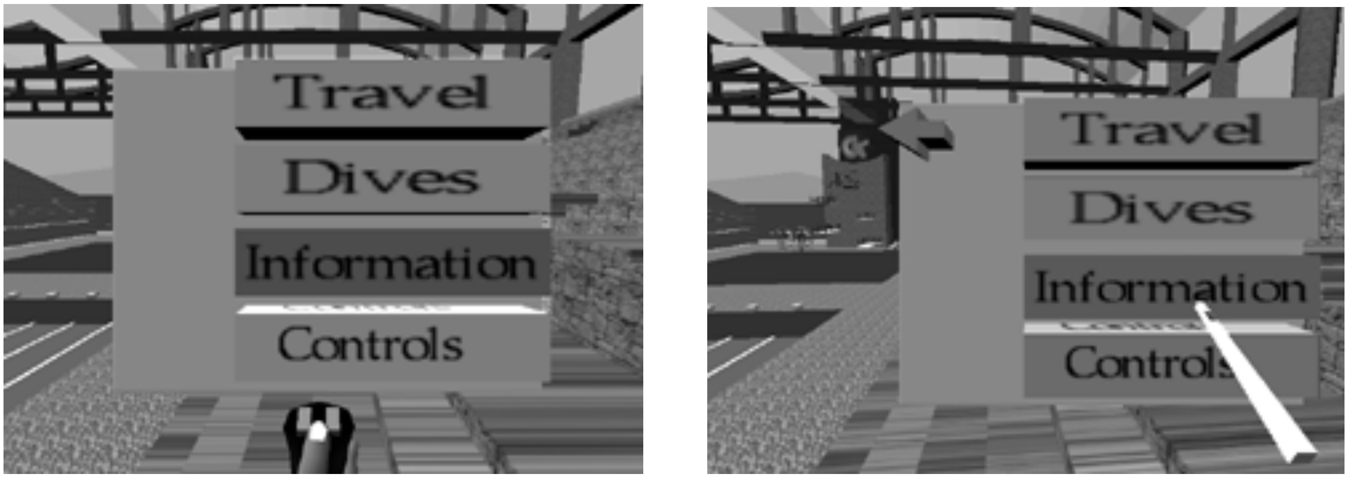
A simple way for the user to control system actions is a necessity in such a highly interactive application. The tool should be consistent, always accessible, non-intrusive, and easy to use. To meet these needs, we have developed a hand-held menu system for our virtual environment.

Figure 2. Physical Devices used in the Virtual Venue

The use of commands in general and menus in particular within a VE has been the subject of some debate. Some feel that all interaction in the VE should be "natural," or similar to the physical world [15]. In our experience, however, we have found that natural metaphors are not appropriate for abstract commands, and that overuse of real-world techniques can lead to system clutter and reduced user efficiency [5]. A good deal of research into virtual menus has been performed [4, 10, 12]. Our approach is closest to that described in [1].

In the Virtual Venue, the user holds a physical tablet, which is tracked in 3D space (Figure 2). In the VE, the user sees a virtual representation of the tablet, on which are printed various menu items. By selecting a widget on the tablet, users either change to a different menu or issue a command to the system. Menus are used for travel through the environment, controlling the actions of a simulated diver, obtaining text information, and setting system controls. The menus are arranged in a hierarchical structure that is several levels deep. We have developed two separate techniques for navigating the menus and selecting menu items.

If only two trackers are available (one being used for the HMD position), a *joystick* is used to control the menu system (Figure 3a). Three buttons correspond to selecting the current item, scrolling down through the menu, and returning to the next-highest level menu.



a. b.

Figure 3. Two Interaction Techniques for Hand-held Menus: a) joystick, b) pen & tablet

If three trackers are available, we use a *pen & tablet* metaphor (Figure 3b). The user touches the desired widget with a stylus and presses a button to select it. Using the same technique, the user presses a back arrow to return to the previous level.

This hand-held menu system achieves all of the goals listed above. It is consistent, since all actions the user takes to control the application are performed using the same technique. The user carries the menu in her hand, so commands are always accessible. The tablet may always be placed to the side or in the user's lap, so it does not obscure the environment. Finally, the system is simple to learn and easy to use, as we will show in the usability study presented below. The pen & tablet metaphor also has the advantage that it can mimic any 2D interface which can be controlled with a single-button mouse, since users can "click" or "drag" on the physical 2D surface of the tablet. This physical feedback provides an important constraint: if the pen is touching the tablet, users are assured that a menu item will be selected [5].

Constrained Travel

A second issue concerns the movement of users around the Virtual Venue. Most VR applications allow the user to travel freely throughout the environment, either "walking" in two dimensions (constrained to a ground plane) or "flying" in all three dimensions [14]. Often, however, users who have freedom of movement become lost or disoriented, or miss important features of the environment [5]. Since our system was not designed to allow users to examine every detail of the 3D model, we developed a more constrained method of travel called the *flying chair* metaphor.

Users sit in a physical chair (see Figure 2), with their feet above the ground. In the VE, a virtual chair and legs may be seen, providing users with a sort of "virtual body" even though their legs and feet are not actually being tracked. Seven locations were chosen in the VE which allowed interesting views of the Aquatic Center and corresponded to information we wished to present. By selecting a menu item or spatial hyperlink (see below) on the tablet, users can travel to one of these positions. The motion is smoothly animated from the current location to the destination, and the virtual chair rotates to face the most interesting view at the new position.

Using this metaphor, we eliminate the possibility that users will become lost or disoriented. They may feel somewhat restricted, since they are only able to travel to a set of discrete locations, but if these pre-defined positions are chosen wisely, users will be able to obtain views of all the interesting parts of the environment, as well as to visit each place where embedded information may be retrieved. The use of constrained travel also allows better information access. By remaining oriented in the VE, finding information is simpler, and users can more easily relate the symbolic information to the environment and vice-versa.

Spatial Hyperlinks

Hyperlinks are used on the World Wide Web and in multimedia applications to link related information that is not necessarily presented in a linear structure. Since we were using text information with many interrelated topics, hyperlinks were a natural addition to our set of interaction techniques. We have also developed a new form of hyperlink which seems to be especially effective in an immersive VE: the *spatial hyperlink*.

Spatial hyperlinks relate text information back to the environment in which the user sits. For example, suppose the user is reading a page of information about diving world records, which mentions a record for the 1-meter springboard event. To relate this information back to the environment, the user needs to know where the 1-meter springboard is, what a diver would see when preparing to dive from it, etc. By selecting a spatial hyperlink over the words "1-meter springboard," the user is automatically transported, via the flying chair, to the diving board within the environment.

Thus, with a spatial hyperlink, the user does not simply access new information. Rather, he actually experiences a new location in the virtual world. The text information becomes more closely related to the three-dimensional environment, and the experience is enhanced. In the section below on information access, we discuss how the environment may be related back to text or audio information, completing the loop.

Audio Help

Our environment is designed for instructional purposes, so the target audience consists largely of first-time users. The system will probably be the first VR experience for many of these users as well. Since users are expected to be quite active, not simply viewing their surroundings, it was necessary to provide a help system to guide users through the application. We chose to present help through the audio modality, so that users could look at the relevant parts of the environment or interface while listening. This would not be possible with a text-based help system. Audio help appears in two contexts.

First, there are a number of *help icons* scattered throughout the environment. These are simply cubes with an icon on the sides representing sound. They are positioned to be easily seen from the known positions of the flying chair. By selecting the icon (more on the selection technique later), users hear context-sensitive help on relevant actions they can take while at that location. For example, a help icon placed above the diving platform instructs users how to see a simulated diver perform (see Figure 4).

Second, spatial hyperlinks provide *automatic help* when they are the focus of the user's attention. When the user touches the link with the stylus, it provides visual feedback and plays a short sound explaining the action that will be taken if the link is selected.

This audio help is non-intrusive: it allows users to continue interacting with the system while it is being played. Users can also disable audio at any time if they do not desire to hear the help. This help system provides the right balance of prompting users when they need it while not distracting them from the other interesting features of the environment or the embedded information.

Information Types

The Virtual Venue as an information space has a rich variety of content. Information was gleaned from Web pages, newspaper articles, record books, and drawings. We attempted to include a wide range of information types to enhance the virtual Aquatic Center.

The most ubiquitous category of information is *simple text*. Text is available describing the building, the swimming pools, the seating capacity, swimming and diving world records, technology used in the Center, and so on. Some of the text includes spatial hyperlinks as described earlier. Text is presented to the user directly on the interface tablet. In this way, the text is always available no matter where the user is in the environment. Also, the tablet may be brought closer if the user wishes the text to be larger for readability.

We also make use of a good deal of *audio* in the Venue environment. Besides the previously discussed audio help, we also use audio for two other purposes. First, environmental sounds are played when appropriate. These include a cheering crowd in the seating area and a splash when the diver dives into the pool. Second, many objects in the VE are annotated with audio. When the user selects such an object, she hears its name spoken aloud.

Image information is also available. Specifically, we have collected various photographs of the Aquatic Center and divers, and placed them on the "scoreboard" in the Center. When the user selects the scoreboard, the image there (along with a caption) changes. By continuing to select the scoreboard, the user can see a virtual slide show of the available photos.

As we have mentioned previously, we have also included a physically simulated diver [20] in the environment (Figure 4). The diver performs three different dives, and his speed may be controlled by the user. This is an example of *animated 3D information*, which is an information class that is difficult to present in more traditional settings. It is especially effective in an immersive virtual environment, because the user can examine the animation from different points of view in order to gain knowledge about the dive.

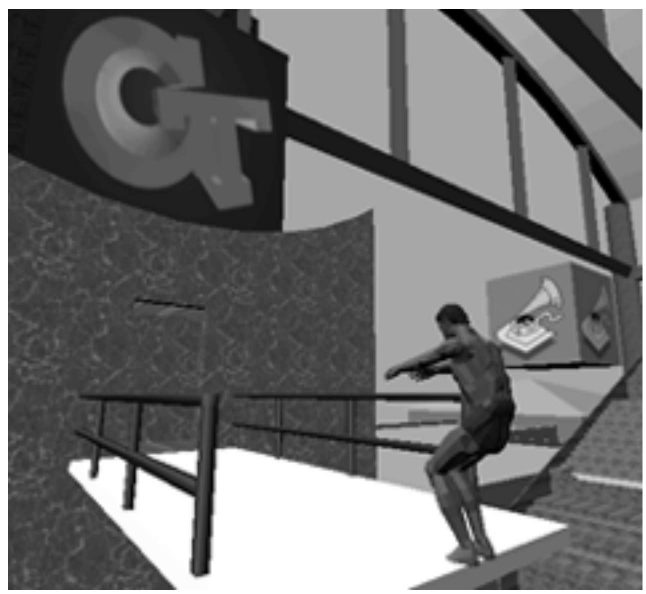


Figure 4. Simulated Diver with Audio Help Icon

Finally, we have embedded what we call *experiential information* within the Virtual Venue. This type of information allows the user not only to view, but also to experience or "feel" informational content. For example, the user may choose to follow the diver from the starting position on the 10-meter platform all the way down into the pool. In this way, the user can examine the dive more closely. More importantly, however, the user experiences something of the speed of the dive and the force of gravity pulling the diver toward the water. Also, there are spatial hyperlinks within the text describing world records in swimming. Selecting these links cause the user to "go swimming," allowing him to experience the distance involved in a given event, such as the 100-meter freestyle.

Information Access

Given all this content, it is important that users have consistent, simple, and efficient techniques for accessing the information. Three main methods are used in the Virtual Venue for information access and retrieval.

First, much information may be obtained by choosing an item on the *interface tablet*. This is an indirect technique, but it is an efficient one if broad information is desired on a specific topic, since the tablet is always available to the user. Abstract text information is accessed with this method, such as a list of events held at the Center, or information on technology used there. The tablet is also used to trigger the simulated diver and the different types of experiential information, through menu items or spatial hyperlinks.

Second, text and/or audio may be retrieved by *direct selection of objects* in the VE. We wanted users to be able to select objects no matter their position in the environment, rather than only being able to select objects which they could touch. Therefore, we implemented a ray-casting technique [14], in which the user points a light ray at the object of interest. In our application, the stylus is also used for this purpose. If the stylus is not touching the tablet, pressing its button causes a light ray to emanate from its tip. When the ray intersects a "hot" object, the object changes color, and the user simply releases the button to select the object. This technique is easy to use and powerful, since any object in the field of view may be selected. We used this method for the retrieval of text specifically tied to an object, such as the dimensions of the diving pool, as well as to obtain the names of objects via audio clips. This selection technique is also used to select the help icons and the scoreboard described earlier.

Finally, some audio information is obtained via *context-sensitive, automatic retrieval*. Sounds related to a certain area are triggered when the user enters that region of the environment. For example, when the user is taken to the swimming pool via the spatial hyperlink, he hears the splashing water as he "swims" the length of the pool. Other locations also contain environmental sound or spoken information that plays automatically.

USABILITY STUDY

In order to test our hypotheses about embedded information in a virtual environment, as well as the interaction techniques we had designed to access that information, a usability study was performed. Ten evaluators participated, all of whom were students. Both graduate and undergraduate students, and both technical and non-technical majors were represented. None of the users had any previous experience with immersive VR. The usability study was designed to exercise all the features of the system, and to put an emphasis on ease of use, ease of learning, and efficiency.

Structure and Content

As discussed earlier, we designed two different interaction techniques for operating the hand-held menu system: one using a joystick, the other a stylus. In the usability study, these techniques were compared against one another. Therefore, the ten evaluators were divided into two groups, one group for each technique. Evaluators were not told of the other menu technique until after they had completed the entire study.

Except for this distinction, the study was the same for both groups. After completing a consent form and background questionnaire, users performed some tasks in the immersive Virtual Venue system. The task section was divided into three parts. Evaluators were timed on each individual task, errors were noted, and a detailed log of user actions was kept by the system.

In order to test ease of learning, the first set of tasks was designed so that users would learn the main interactive techniques on their own. After donning the head-mounted display, evaluators were given no instruction on the use of the menu system or object selection light ray, except that it was possible to select menu items or objects, using the buttons on the joystick and/or stylus. The tasks in this first part were simple and redundant, so that speed of learning could be measured. Tasks involved the use of only one of the four top-level menus (travel), so that other system functionality would not be revealed until later.

Second, the users entered an exploration phase. Here, evaluators were allowed to use the system freely for ten minutes, so that they would become acquainted with the rest of the application, such as the simulated diver, the controls menu, and the use of spatial hyperlinks. Again, no instruction was given, unless the evaluator had failed to find one or more of the major techniques at the end of the ten minutes.

Finally, a set of more complex tasks was presented. These involved multiple actions on the part of the evaluator, and often multiple interaction techniques. This section was designed to test the evaluator's overall system knowledge, including the structure of the menu system, object selection, use of spatial hyperlinks, and access paths for specific pieces of information.

The study concluded with a feedback questionnaire and interview with the evaluator.

Results

The usability study provided us with a great deal of useful data about both the usefulness of immersive VR in information retrieval and the types of interaction techniques which are usable and efficient in such a system. The main results are summarized below.

Embedded Information

As we have noted, the first major issue is whether the use of embedded symbolic information in a perceptual environment is useful or enhances the information. In our study, the comments from evaluators were mixed, but show a definite trend.

Of the information types which were embedded in the virtual venue, the experiential information, the spatial hyperlinks, and the information embedded within specific objects were the most highly praised by our users. Users did not feel that the plain text information, accessed via the menu, or the image information presented in slide show format, were as useful or relevant.

This leads us to the observation that those information types which are the most enhanced for the user and enjoyed by the user are those which are *tightly coupled* to the perceptual environment. Experiential information allows the environment itself to be utilized as a conduit for information. Spatial hyperlinks directly relate text information to locations or actions within the environment. Finally, information embedded in objects completes the circle, relating the 3D world back to symbolic (text or audio) information.

Hand-held Menu System

The menu system is the major interaction technique used in the Virtual Venue, so evaluators' ability to learn and use the menu was especially important to our results. Both interfaces were well received and performed efficiently.

The pen and tablet interface proved especially easy to learn and use. Without instruction, most evaluators used the technique correctly the first time and times remained low for subsequent tasks (Figure 5). The joystick interface, while more indirect and less intuitive, still scored well. It took most evaluators only one or two menu tasks before they understood the mappings of the three buttons, and times then decreased to approximately the same level as those using the stylus technique (Figure 5).

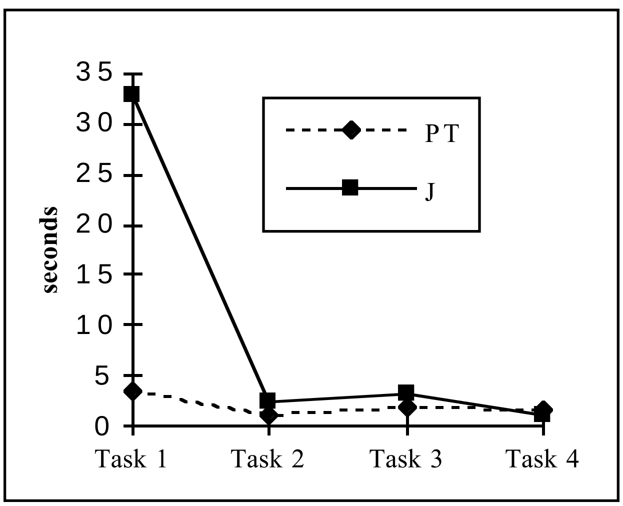


Figure 5. Comparison of Menu Interface Techniques for four simple menu selection tasks. PT: average times for Pen & Tablet Technique, J: average times for Joystick.

Qualitatively, users preferred the stylus interface for ease of use. On a scale of -2 to 2, with -2 representing "quite hard to use" and 2 representing "very easy to use," stylus users rated the interface at 1.2, while users of the joystick interface rated it at 1.0. However, overall system satisfaction ratings were quite high for both groups (1.4 for the stylus group, 1.3 for the joystick group), even though much of the session was spent using the menu system. Overall, timings and observations showed that the stylus group tended to learn the interface more easily and make fewer errors. However, the joystick group acted more quickly and efficiently. Once the evaluators understood the button mappings, they were often able to "click ahead" of the system, producing better times on some of the more complex menu tasks.

Overall, then, both interfaces performed well. The structure of the menu was not difficult for most users to follow, and every menu task was completed by every evaluator. Use of the stylus and tablet seems to be most suited for novice users who need an intuitive and uncluttered interface. The joystick can be more efficient, however, if users are willing to spend a few minutes mastering it.

Constrained Travel

In one sense, the flying chair metaphor worked perfectly during the usability study. Not a single user became lost! Evaluators were able to remain seated for the entire session, moving only their head and hands. Although we have no proof, this may have been a significant reason why no users became dizzy or nauseated during the study, even though sessions usually lasted more than thirty minutes.

On the other hand, many evaluators commented that they felt restricted by this travel metaphor, and that they would prefer more freedom of motion to see more details of the environment. This may be partly explained by the fact that none of our evaluators had ever experienced immersive VR before, and wished to look at the 3D environment more closely than they would had they used similar systems in the past. However, the flying chair metaphor does trade freedom for greater precision, efficiency, and user orientation. On average, users rated the flying chair at 0.6 on a scale of -2 to 2, with -2 representing "quite ineffective" and 2 representing "very effective."

One possible solution might be to augment the flying chair metaphor to allow users some freedom of motion while still adhering to the main concept of pre-defined positions to which the user is taken. Users could be allowed to move around within a certain range of each of the main destinations, and the system could ensure that they would not travel through walls, floors, or ceilings.

Information Access Techniques

Other methods for retrieving information within the VE were also tested. Most notably, the study focused on the use of the ray-casting technique for object selection.

Selecting objects in 3D was a foreign concept to most of our evaluators. Again, they were given no instruction in the use of the stylus or light ray and were required to discover the technique on their own. There were three tasks in the first task section which required users to select objects in the environment. The average times for these tasks (43.56, 6.78, and 12.56 seconds) indicate that after the initial task, users were able to use this technique fairly efficiently and accurately.

We made one important observation in the use of this interaction technique. Since most evaluators were familiar with the desktop metaphor and 2D GUIs, they associated object selection with a "point-and-click" action. The light ray, however, requires a "press, point, and release" to work correctly. This misconception led many users to try to point the stylus in approximately the correct orientation in 3D, then click the button.

For novice users, then, it might be beneficial for the light ray to be active at all times when the stylus is not touching the tablet. In this way, users can highlight the desired object and then click the stylus button. In other words, they would use a point-and-click metaphor.

On the whole, object selection using the light ray worked as expected. Once the technique was mastered, evaluators were easily able to select objects, even from a great distance. Because users did not have to travel to an object to select it, efficiency was maintained and large objects could be seen in context during selection.

CONCLUSIONS AND FUTURE WORK

Through the Virtual Venue project, we have learned a great deal about the utility of virtual reality for the purpose of information retrieval and enhancement. It is clear that embedded information can be augmented for the user if it is closely related to and tightly coupled with the virtual environment. We have also seen that the use of appropriate symbolic information can make the experience of immersion in a virtual environment more engaging and relevant.

In the area of interaction techniques, we have developed a useful and usable suite of tools. The hand-held menu is a user interface that is coming closer to maturity. The concept of bringing 2D metaphors into the virtual world no longer seems unnatural or backward. Rather, these familiar techniques translate well into 3D, and users are often able to complete tasks more quickly and easily than by using gestures or real-world metaphors exclusively [18].

Spatial hyperlinks are another innovation that we believe will be an important technique to relate static information back to a dynamic environment. Furthermore, our 3D object selection technique works well as a parallel to traditional 2D pointing methods.

In the future, we hope to put our theories of embedded information to an even more complex test. We propose to compare the utility and learning support provided by several different information access scenarios. These will include the printed page, hypertext documents, non-immersive 3D environments, and immersive VR.

We also plan to continue our development of interaction techniques for information access as well as for general user tasks in immersive virtual environments. One interesting possibility that we have already explored briefly is a general tool for database access from within a VE. If the VR application is directly linked with a database related to the environment, embedded information could be changed and updated on the fly. A tablet interface similar to the one described here can be used to specify queries to the database. Results would not only be shown in text-form, but would also be linked back to the environment as spatial hyperlinks. Objects could still be selected directly, providing easy access to data related to the object.

ACKNOWLEDGMENTS

The authors would like to acknowledge the help of our evaluators, whose time and comments are greatly appreciated. We also acknowledge the use of the physically simulated diver, developed by Wayne Wooten and Jessica Hodgins of the GVU Animation Group. This work was supported in part by the National Science Foundation and the Hewlett-Packard Corporation.

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